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ATR-74(7336)-3, VOL. I

Operations Analysis (Study 2.6) Final Report

Volume I

Executive Summary

Prepared by ADVANCED VEHICLE SYSTEMS DIRECTORATE
Systems Planning Division

15 September 1973

Prepared for OFFICE OF MANNED SPACE FLIGHT
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D. C.

Contract No. NASW-2472

Systems Engineering Operations

THE AEROSPACE CORPORATION

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Volume I: Executive Summary

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FOREWORD

This report provides a brief overview of the effort performed under Study 2.6, Operations Analysis. The fundamental objective of this study was to examine alternative means of improving the utilization of the STS system for future space program applications.

The study assesses the efficiency of Shuttle and Tug operations based on the 1971 mission model. An alternative excursion of this mission model, issued in 1972, was also examined to assess the sensitivity of the STS to accommodate mission variations. Tradeoffs were performed on various upper stage candidates relative to the overall space program benefits. This included cryogenic and storable upper stages as well as Solar Electric Propulsion Stages (SEPS).

Space servicing of payloads is also examined relative to reducing overall program costs. Thirteen payload programs at synchronous equatorial orbit are examined, making up a total operational complement of 37 satellites. The impact of payload redesign and servicing operations is assessed against ground refurbishment of payloads as an operational concept.

This volume is one of four volumes comprising the final report of Study 2.6. The remaining volumes are listed below.

Volume II	Analysis Results
Volume III	Payload Designs for Space Servicing
Volume IV	LOVES Computer Code Specification

Study 2.6, Operations Analysis, is one of several study tasks conducted under NASA Contract NASW-2472 in FY 1973. The NASA Study Director was Mr. V. N. Huff, NASA Headquarters, Code MTE.

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1. INTRODUCTION

This study was initiated to examine alternative STS operational concepts for the future which would have the potential of providing economic benefits. The study examines the total concept at a system level involving mission requirements, payload design options, and logistic vehicle definitions. The problem is approached in a generic sense because, while payload and missions of the future can be assumed to be an extrapolation of today's missions, detailed payload design information is currently unavailable. The emphasis of this study has been directed toward assessing typical mission characteristics and searching for alternative means to improve the operational capability of the STS system as a whole.

Improved utilization of the Shuttle and Tug upper stage for payload deployment and retrieval was addressed first. This leads to increased multiple payload operations to maximize the loading efficiency of these vehicles. Further improvement was developed by modifying the payload design and operational approach to allow space servicing with the promise of future economic improvement. Multiple mission satellites and alternate upper stages were also examined, including a brief look at Solar Electric Propulsion Stages (SEPS) and in-space warehousing of space replaceable payload modules. Although the results presented in this report are constrained by input assumptions and ground rules, the conclusions strongly point toward new space-servicing concepts which inherently improve the efficiency of future space operations.

The study approach was developed around three major elements of the NASA space program: payloads, missions, and logistic vehicles. The first element addresses the payload definitions as provided in the NASA Payload Data Book, which describes candidate payload programs for the 1979 to 1990 time period. The initial interest was directed at the compatibility of multiple payload/logistic operations. As the study evolved, interest developed in space servicing as an operational concept, and consequently payload modularization was employed based upon LMSC and

Aerospace design approaches. The second step consisted of analyzing various approaches for deploying and servicing multiple payload operations. This was based upon the 1971 NASA mission model and the 1972 excursion. Impulse requirements to phase from one position to another in the same orbit were determined along with plane change maneuvers. High energy and low altitude orbits were also analyzed. The third step addressed candidate logistic vehicle concepts. The Shuttle was assumed to be relatively fixed in its design. However, upper stage concepts vary considerably from low technology cryogenic stages to the Marshall Space Flight Center (MSFC) baseline Tug and also include storable upper stages. In addition, when considering upper stages, a Solar Electric Propulsion Stage (SEPS) offers certain advantages. Tradeoffs between various upper stage options, including tandem Tug operations, were performed relative to total program costs.

In summary, the results of various tradeoffs performed during this study point to space servicing as a means of reducing overall program costs including payload acquisition and logistic vehicle operations. Space servicing in turn, implies the use of standard modules for housekeeping subsystems, although deviations can be tolerated in specific instances. A further extension of this concept leads to multi-mission satellites in which a common set of subsystems may support several payload programs simultaneously (time-sharing operations) or allow mission equipment changeout. For many of the NASA payload programs the mission equipment is the major source of uncertainty in future planning rather than subsystems. Reliabilities of multi-spectral scanners and similar equipment are relatively low and can be projected to have no more than a two-year operating life in the time period of interest (1979-1990). Since these equipments are mechanical in nature, the failure modes exhibit wearout features rather than random failures, and consequently redundancy is often difficult to achieve. Space servicing therefore offers a means of maintaining and upgrading mission equipment at a reduced program cost if standardization of the operating concept can be achieved; that is, if efficient utilization of the Tug to service several payloads on a single mission is possible.

2. BASIC DATA DEVELOPMENT

An extensive amount of basic data is required to support space servicing tradeoffs. Examples of the types of information required are given along with some of the analysis results which led to space servicing as a concept. The information is separated into three principal subjects:

Mission characteristics
Logistic vehicle options
Payload design options

A. MISSION CHARACTERIZATION

It is important in assessing operational concepts to determine whether the results are overly sensitive to the initial mission model. In this case, the interest lies in the application of multiple payload logistic operations such as deployment, servicing, or retrieval of more than one payload on a given Tug flight. A measure of the efficiency with which the operations can be performed is the load factor achieved on each flight. The 1971 NASA mission model is used as a basis for this analysis. Excursions are then made to see if the logistics vary significantly. The following questions were addressed:

1. What load factor (and volume factor) was achieved for each logistic operation?
2. To what extent were multiple payload operations employed?
3. What potential exists for improving the efficiency of flight operations?
4. What uncertainties exist which may alter the derived results?

The following information summarizes the efficiency of utilizing the STS when addressing the 1971 mission model. The Shuttle is used to transport payloads to a 296 km (160 nmi) orbit at 28.5 degrees inclination. Over the expanded time period of 1979 to 1997, the average load factor was 80 percent for the total of 331 flights. The next leg resulted in 191 Tug and ten tandem Tug flights to synchronous equatorial orbit. The average load factor for Tug operations was only 67 percent, with approximately 50 percent of the flights handling a single payload up and a single payload down. Forty flights had a load factor less than 30 percent with several flights below 10 percent. In summary, improved utilization of the Tug is needed and further improvement of Shuttle flight efficiency is desirable.

An example of alternative applications of the Tug to improve its utilization is seen by examining operations for polar orbits. An examination of the current mission model shows that the Tug load factor for operations at the Western Test Range is less than 5 percent. This is based upon multiple payload operations wherever the same orbit is employed. One option is to use a smaller Tug, since the baseline MSFC Tug must be off-loaded for these flights anyway. Another option is to use a storable stage, which is more in line with the impulsive velocity requirements. However, utilization of the baseline Tug can be improved substantially by allowing multiple-orbit operations, including plane change maneuvers.

Figure 1 shows the launch window associated with Tug flights for polar elliptical orbits. The Tug flight originates from a circular orbit of 185 km (100 nmi). Transfers are then made to three other orbits as shown. After servicing each orbit, the Tug then returns to the Shuttle orbit, all within a seven-day period. The payloads involved are the NC2-48 small ATS and two Explorer Satellites, NP2-13 and NP2-14. As shown, the Tug has the capability to service all three orbits on nearly a continuous basis, depending upon the service weight involved. Even though the line of apsides of each orbit translates relative to the other orbits, the Tug has an available launch window 90 percent of the time. Using this approach improves operations to the extent that the previously scheduled Shuttle/Tug operations for these payloads could be reduced by 30 percent.

B. LOGISTIC VEHICLE OPTIONS

A brief review of logistic vehicle options is provided here to indicate the type of data which must be developed to support space servicing. Space servicing of multiple payloads in a given orbit requires the logistic

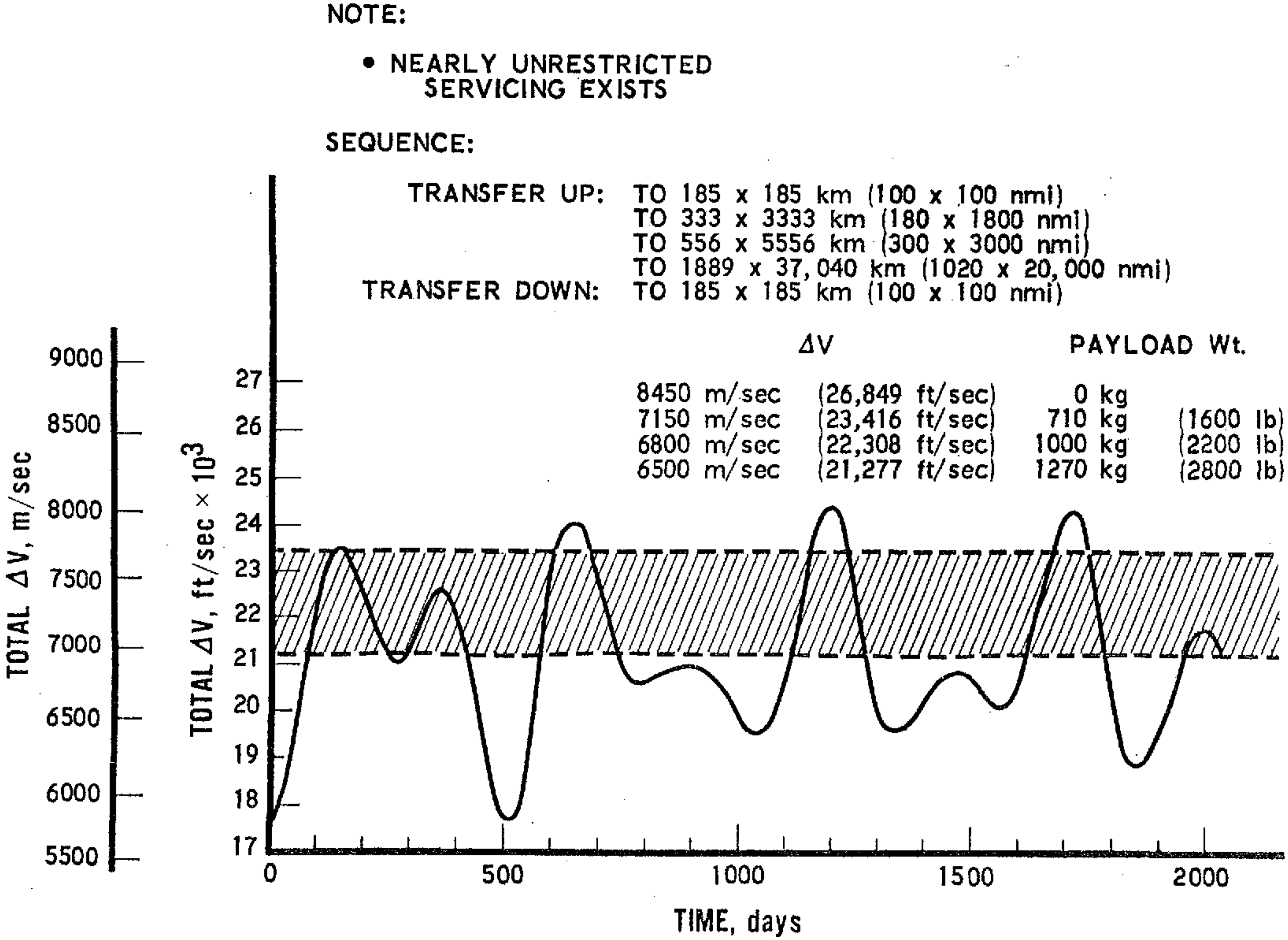

Figure 1. Payload Capabilities of Off-Loaded Tug for Servicing Three Elliptical 90-deg. Orbits

vehicle to transfer from one payload to another, exchanging modules or performing some other service. Particular interest lies in synchronous equatorial orbits, where a majority of the projected payload programs will be deployed. In this application, it has been assumed that the servicing weight is constant for the entire operation. That is, if a module is to be taken to a satellite, the module removed is equivalent in weight, and consequently the service weight on the Tug remains constant. This represents a conservative assumption but eases the interpretation by allowing parametric data to be developed.

The baseline Tug capability to perform servicing is shown in Figure 2 and is restricted to a seven-day mission duration. The number of satellites to be serviced are distributed equally over the total phase angle being considered. The Tug mission duration is highly restrictive, due to the long period of the transfer orbits required to change longitude placement. However, even with this restriction, the Tug could service three to four payloads if the satellites were clustered over a limited phase angle, say 120 degrees. Allowing 91 kg (200 lb) for a servicing unit, the Tug could replace 204 kg (450 lb) of equipment in each of four satellites. This is not unrealistic considering the distribution of payloads in synchronous equatorial orbit. Extending the Tug mission life to 21 days provides a substantial improvement in servicing capability. As many as six or more payloads could be serviced over a 300-deg phase angle.

Applying this same idea to the use of a Solar Electric Propulsion Stage (SEPS) stationed at synchronous equatorial orbit results in a further increase in capability within reasonable time constraints. The SEPS can translate 4,536 kg (10,000 lb) of payload through a phase angle of 180 degrees in approximately 12 days. It can service three payloads at 90-deg positions with 4,536 kg (10,000 lb) in 16 days. If space replaceable units (SRUs) could be warehoused in orbit (i.e., deployed by a tandem Tug), the SEPS has sufficient capability to service payloads with a response equal to or better than ground-oriented Tug operations. Detailed tradeoffs were not possible within the current study, but this concept

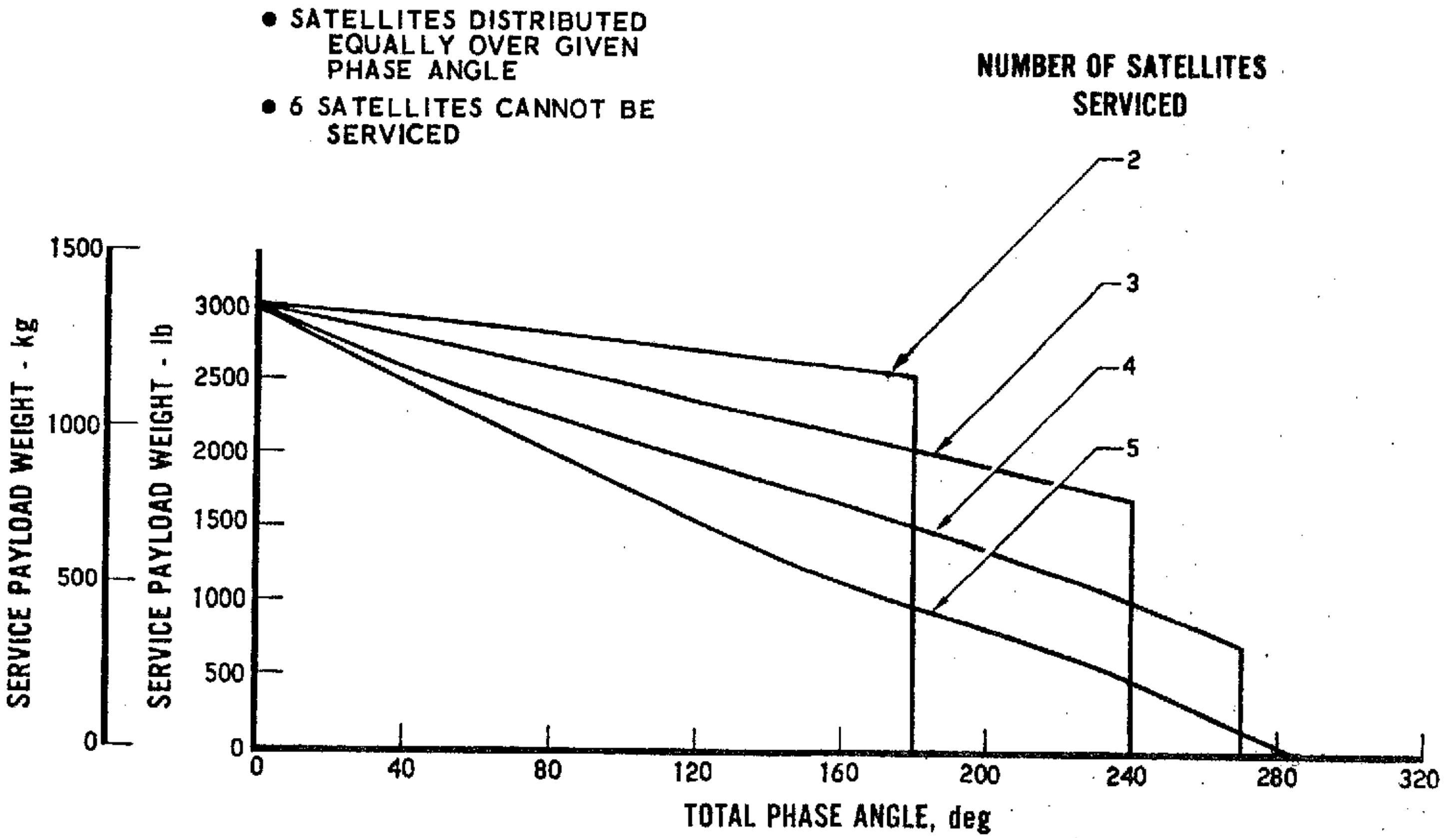

Figure 2. Tug Service Capabilities for Seven-Day Operating Period

deserves consideration in any follow-on efforts.

C. PAYLOAD DESIGN OPTIONS

Payload design has been considered only to the point that sufficient information can be developed to support system level tradeoffs. The desired information is generic in nature, allowing extrapolation to all of the payload programs of interest. The payload configurations evolved from a conceptual design study performed at Aerospace for SAMSO. Data from other payload programs within Aerospace were also employed in developing reliability and weight characteristics. For the most part, all of the design information employed should be considered conservative in that further refinement could produce lower weights and higher reliabilities.

A brief review of payload failure histories was conducted to aid in selecting the levels of redundancy to be considered. Of the failures identified, 93 percent represented a condition classed as small to negligible degradation; 5 percent represented a significant degradation; and 2 percent resulted in loss of the spacecraft. Where redundancy was employed, it contributed nearly as many anomalies as it protected against. Consequently, experience indicates that redundancy as a means of achieving an operational lifetime is not altogether effective. This implies that a majority of failures are not random, but rather are design deficiencies, due either to improper design or a poor knowledge of the environment. Although the reliability of satellites should continue to improve with experience, it can be expected that these two factors will dominate the failure characteristics.

Space servicing provides one means by which satellites can be maintained in an operational condition. If the failure occurrence of a particular element is determined to be a design deficiency, the design can be corrected and then installed in all satellites with common equipment. Redundancy would not necessarily provide the same operational capability. It is prudent, however, to maintain a minimal level of redundancy or redundant modes to support serviceability, if required. As an example, backup attitude stabilization should be provided to allow docking. Backup transmitters should also be provided to support diagnosis of the failure condition. Therefore, for the current study, redundancy of satellite components has been minimized, allowing sufficient room for incorporation if the analysis results so dictate.

Another key item in considering space servicing as an operational concept relates to payload availability. This term represents the ratio of time the payload is operating on-orbit to the design life of the satellite. A 95 percent availability implies that 5 percent of the time the satellite is not functioning as desired or to minimum specification. The user requirements are unknown, but would obviously vary over a wide range, depending upon the value of the data being obtained. The Aerospace studies performed for SAMSO were directed toward maintaining a high availability for national security. Non-NASA domestic ComSats desire a high availability because of a direct relationship to revenues. However, NASA experimental and developmental satellite programs may not require a high availability, due to the associated logistics costs. Since a valid criterion does not exist, this parameter will be treated as a variable in subsequent analyses. Because of its importance to the servicing policy, the term will be mentioned repeatedly.

Payload design information has evolved from several sources. In the final selection of data, it should be recognized that a certain degree of engineering judgment was required to compile a sufficiently complete set of data to support trade studies. The major source of payload design information was developed by reconfiguring the NASA Earth Observatory Satellite (NE2-38 EOS) to be space serviceable. The reconfiguration was based upon the initial work performed by Aerospace on the Defense Support Satellite (DSP) program utilizing common detail design approaches, where applicable. The principal reason for this selection is that the payloads are modularized around a 3.0-m (10-ft) diameter ring frame. The entire payload will fit into a volume of 4.6-m (15-ft) in diameter by approximately 1.5 to 2.4-m (5-ft to 8-ft) in depth. With this approach multiple payloads can be assembled in the Shuttle payload bay, making better use of the available volume constraints.

A view of the referenced EOS is shown in Figure 3. This figure also shows the space serviceable concept. The mission equipment sensors have been

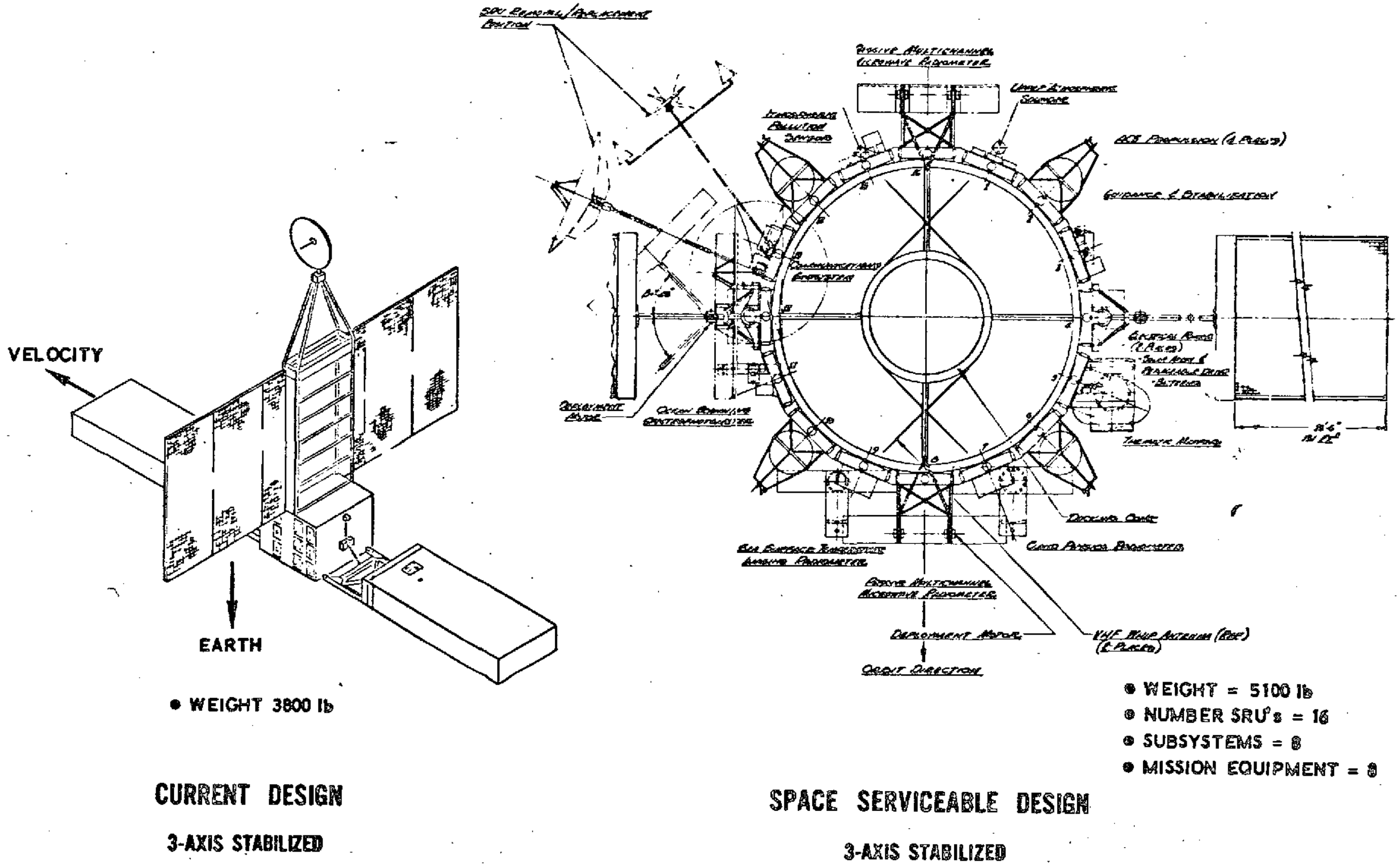

Figure 3. EOS Payload Reconfiguration

packaged as independent modules. The remaining modules accommodate subsystems. Several alternatives are available in terms of new mission equipment, alternate attitude control systems, etc., but, for the purpose of this study, the design is sufficient to bracket module sizes and weights. The payload weight increased from 1,724 to 2,313 kg (3,800 to 5,100 lb). A more compact design could be achieved, but this approach was considered to be reasonable and conservative. Each module was defined to the component level to allow development of reliability block diagrams. The reliability data were then used to predict random failure times of the individual modules.

The reliability definitions are the major point of concern. The sophisticated sensors employed for earth observations have a current operating life of approximately six months. Extrapolating to the 1980 time period provides an upper bound judgment of a two-year design life. It appears impractical to expect longer time periods. It also is impractical to enhance this life by adding redundancy because of the wearout nature of the failure modes. Deterioration of the mission data simply progresses to the point of being unusable. Redundant modules (sensors) could be employed on high priority satellites, but the dormant failure rates have been estimated to be between 25 and 50 percent of the active failure rate. Consequently, redundancy might add one more year of operation at best. Therefore, the mission equipment was treated as non-redundant modules.

The final element in the design process is the service unit attached to the front of theTug. This design was developed for the Defense Support Program (DSP) study. The service unit as shown in Figure 4 consists of space replaceable units (SRUs) around the periphery of an indexing ring frame. At least one spare slot exists to accommodate the failed module. After removing the failed module, the ring frame indexes such that the replacement module is aligned properly with the payload. The module is then translated into the payload, automatically engaging electrical contacts. Numerous design approaches by other contractors have been postulated, but for the purpose here the only important factor is the weight. The design weight has been estimated at 91 kg (200 lb) which is less than for DSP as a result of a reassessment by weights personnel.

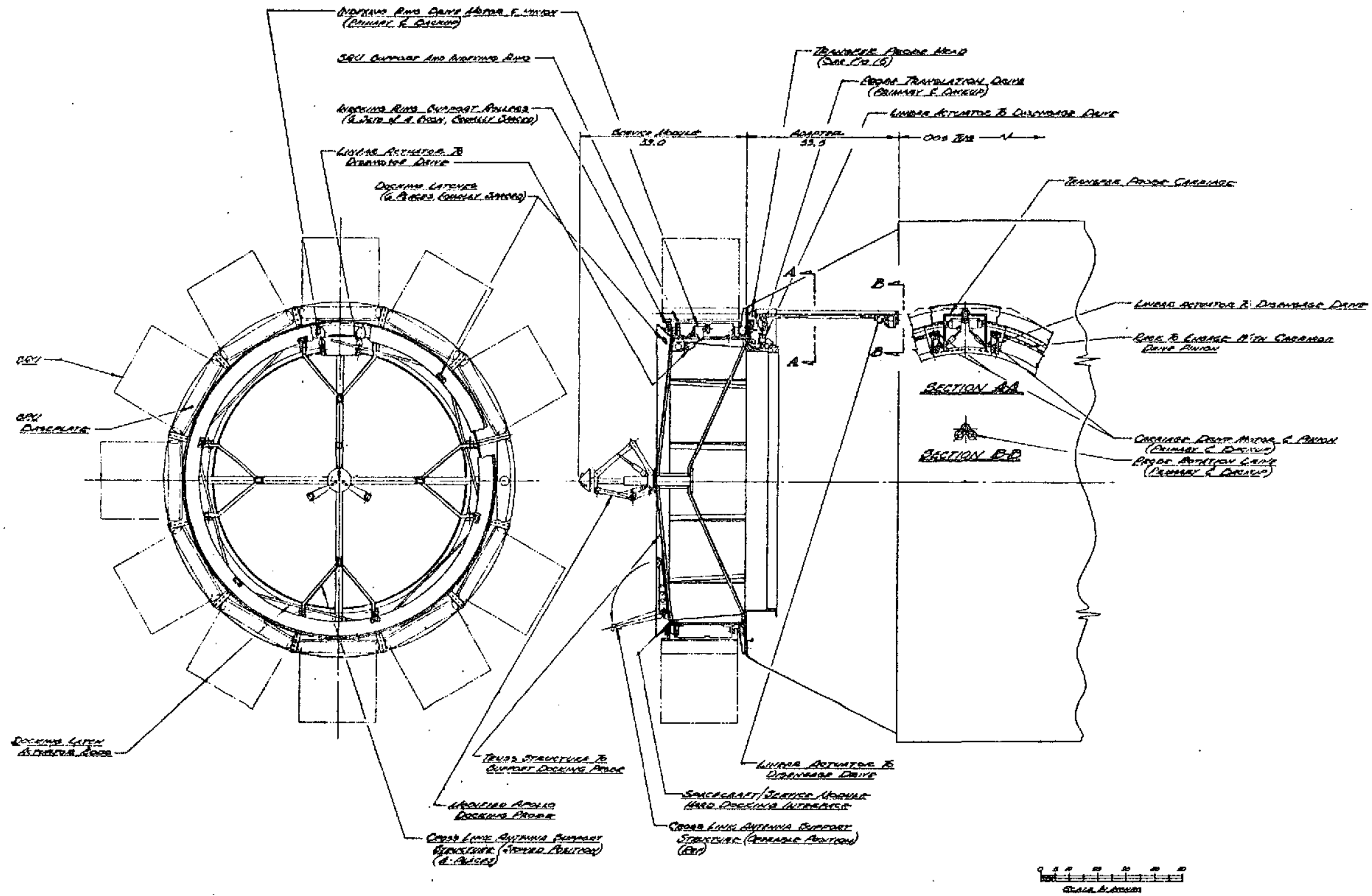

Figure 4. Space-Servicing Unit/Tug Arrangement

3. SPACE SERVICING CONCEPTS

Numerous approaches to space servicing can be postulated depending upon such factors as availability, logistics costs, standardization of SRUs, etc. The purpose of this section is to describe the analysis technique for addressing the parameters and to define the ground rules used in two cases analyzed in this study. An extensive amount of work is yet to be performed; consequently the information developed under this study can only point toward trends relative to the cost of future operations if space servicing is employed. The major points of concern can be summarized by the following questions.

1. Will total program costs be reduced by space servicing?
2. Will individual payload program costs be reduced by space servicing?
3. Can system availability be maintained?

Space servicing will have a major impact on payload and logistic vehicle designs. This impact in risk and cost must be weighed against potential gains. The approach taken to perform this analysis is shown schematically in Figure 5. This is a simplification of a rather complex process but should serve as a basis for the results presented in Section 4. The basic payload data is used to develop generic sets of subsystem and mission equipment module weights, reliabilities, and costs. Candidate payloads from the NASA mission model are then constructed from the module inventory, allowing for basic structure, consumables, etc., as necessary to achieve a representative weight for each payload program. The estimated time to failure is then developed for each module, both space replaceable and non-replaceable, by a random number process. This defines when servicing is needed, and the replacement module is then placed on the manifest to be shipped to orbit. When a sufficient load has been established, the failed module is replaced and returned for refurbishment. The cycle is repeated over the time period of interest.

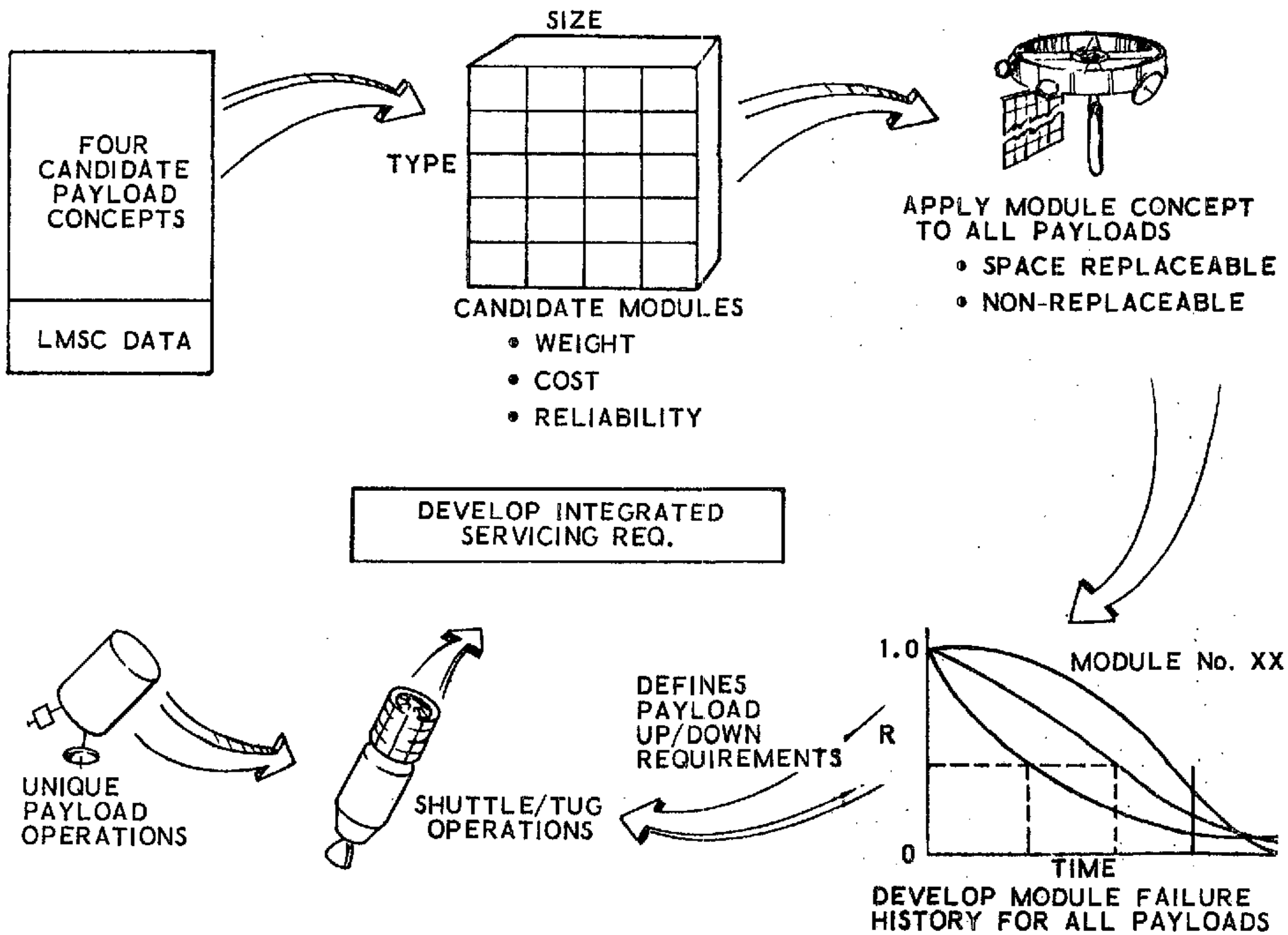

Figure 5. Space-Servicing Analysis Approach

The results are integrated with other payload programs which are not space serviceable to obtain total traffic requirements. The logistic costs can then be apportioned between the various programs according to weight or volume criteria. Further, although some payloads may not be serviceable, they may be modularized. The integrated number of modules, by type, is required to develop the cost profile and production rate.

Certain ground rules have been employed in the process of selecting candidate payloads for space servicing. Planetary payloads have been excluded for obvious reasons; however, if cost benefits accrue, the payload could be modularized. Man-tended programs such as High Energy Astronomical Observatory (HEAO) and the Large Space Telescope (LST) were excluded because dedicated servicing has been scheduled a priori. Also there is little commonality in the design approach with automated payloads. Space station and Sortie modules have been excluded for the same reasons. Finally, small payloads such as Explorers which weigh approximately 136 kg (300 lb) have been treated as single modules and in general will not be serviced. In the sample cases analyzed under this study, the payloads were further restricted to synchronous equatorial orbit to keep the effort within scope. A complete analysis would encompass the total set of candidate payloads.

The candidate set of payloads to be serviced was limited to those shown in Table 1. Detailed information is provided in Volumes II and III, The MSFC baseline Tug was used with a 91 kg (200 lb) servicing unit and an assumed availability in 1979. The minimum time between Tug operations is assumed to be one month and the mission duration is limited to seven days. When new satellites are specified for deployment in a given year, the satellites are assumed to be available on one-month centers. Propulsion units are designed for replacement on three year cycles. Power units are replaced on five year cycles, unless a failure condition forces replacement at an earlier date. Non-serviceable items are designed for an on-orbit lifetime of nine years after which the satellite is retired and a replacement satellite is deployed.

Table 1. Space Servicing Candidate Payloads

SYNCHRONOUS EQUATORIAL ORBIT PAYLOADS					
NUMBER	CODE	NAME	NUMBER IN ORBIT	NASA	NON-NASA
1	NC2-46	Application Technology Satellite	1	X	
2	NC2-51	System Test Satellite	2	X	
3	NC2-47	Small Application Technology Satellite	1	X	
4	NCN-7	COMSAT	3	X	
5	NCN-8	U.S. Domestic COMSAT	3		X
6	NCN-9	Foreign DOMSAT	2→12		X
7	NC2-49	Tracking and Data Relay Satellite	3	X	
8	NC2-50	Disaster Warning Satellite	2	X	
9	NE2-43	Synchronous Earth Observations (Photo)	1	X	
10	NE2-39	Synchronous Earth Observations	1	X	
11	NEO-11	Synchronous Earth Resources	4		X
12	NE2-41	Synchronous Meteorological Satellite	2	X	
13	NEO-15	Synchronous Meteorological Satellite	2		X

4. SPACE SERVICING RESULTS

Although the analysis of space servicing has been limited in its application to high energy orbits, some understanding can be achieved by comparing in a gross sense these results with ground refurbishment of the same payloads as analyzed in previous years. When ground refurbishment of the 13 payload programs is considered, a total of 164 logistic flights are required over the time period of interest. This includes both deployment and retrieval operations based upon a 1983 Tug availability. The flight profile is a composite, made up of Titan IIIC launches and Shuttle launches with Centaur and Agena upper stages. The 13 programs required deployment of a total of 198 satellites of which approximately 60 percent were refurbished, having previously been retrieved.

In addition to the logistics it is necessary to compare the satellite design weights. The low cost design approach assumed for ground refurbishment resulted in a significant weight increase over current design concepts. Space servicing represents, in general, a further increase in total payload weight although the increase is estimated as only 10 to 20 percent depending upon the particular payload involved. The space serviceable designs are composed of seven to thirteen different modules, averaging approximately ten modules per satellite. Of these, approximately 40 percent are mission equipment.

The results of the manual analysis for all 13 payload programs is discussed below. At any one point in time the 13 programs have approximately 37 satellites in operation. This provides a total of over 350 modules with some probability of failure over the time period of interest. It is interesting to find that sufficient traffic exists that, in general, the down time on any given satellite is less than two months. Considering the ground rule that this also includes a 30-day preparation on the ground, it indicates very good accessibility to the failed satellite. Consequently, the availability of any given satellite is relatively high, approximately 93 percent. When two or more satellites are required in a program, the overall availability for the system drops to an average of 81 percent.

The Tug operations are summarized in Table 2. A total of 135 Tug flights is required to service the payloads over the time period of interest. The distribution of flights is such that up to five satellites can be serviced on a single Tug flight. Additional flights involve deployment of new payloads prior to servicing existing satellites. It is also important to note that the full capability of the Tug was seldom used as indicated by the excess performance capability shown. The average load factor was 82 percent which is, coincidentally, the same as achieved for the ground refurbishment operational mode.

Table 2. Case 2 Tug Operations

TUG OPERATIONS		WEIGHT TO SYNCHRONOUS EQUATORAL ORBIT (1979-97)						PERFORMANCE		
TYPE	FLIGHTS	DEPLOYED WEIGHT Kg (lb)	SERVICE #2 Kg (lb)	SERVICE #3 Kg (lb)	SERVICE #4 Kg (lb)	SERVICE #5 Kg (lb)	TOTAL WEIGHT Kg (lb)*	EXCESS Kg (lb)	AVERAGE LOAD Kg (lb)/FLT	LOAD FACTOR PERCENT
DEPLOY ONLY	7	19, 723 (43, 482)	-----	------	------	-----	19, 723 (43, 482)	4, 091 (9, 018)	3, 472 (7, 655)	83
SERVICE ONLY	64	------	748 (1, 648)	17, 748 (39, 128)	16, 403 (36, 163)	3, 230 (7, 122)	43, 935 (96, 861)	15, 151 (33, 403)	686 (1, 513)	74
DEPLOY 1 & SERVICE	54	54, 019 (119, 091)	2, 950 (6, 503)	10, 011 (22, 071)	6, 414 (14, 140)	635 (1, 400)	78, 927 (174, 005)	12, 757 (28, 125)	1, 461 (3, 220)	86
DEPLOY 2 & SERVICE	10	17, 161 (37, 834)	1, 372 (3, 024)	------	------	-----	19, 441 (42, 858)	3, 738 (8, 240)	1, 944 (4, 286)	84
TOTAL	135						162, 026 (357, 206)	35, 737 (78, 786)	1, 198 (2, 645)	82

*91-KG (200-LB) SERVICE UNIT WEIGHT INCLUDED WHERE REQUIRED

5. SUMMARY AND CONCLUSIONS

Logistic operations of the Space Transportation System have several areas needing improvement. Low altitude operations using the Shuttle for payload deployment or Sortie operations show a load factor (based upon weight) of approximately 50 percent. In a few cases, this occurs because of large volume requirements imposed by the payload, but in general it can be laid to poor utilization of the Shuttle. The traffic requirements are so unique that multiple payload operations cannot be exploited. Polar missions were found to result in poor utilization of the Tug. The Tug load factor on the average was less than 5 percent. Several options are available. The orbital requirements are such that (unless there is some mission constraint) up to three payloads in different orbits could be deployed or retrieved on a single Tug flight. The operation becomes complex but the logistic cost is reduced to one-third of the cost previously considered. Another alternative is to use a smaller Tug that is more compatible with the mission requirements. The logistics could be reduced because the Shuttle would have the capacity to deploy other payloads at low altitude on the same flights. A two-stage operation could then be employed where necessary for synchronous equatorial operations. Another alternative that was investigated involved the use of a Solar Electric Propulsion Stage (SEPS) in conjunction with a Tug. A preliminary analysis indicated minor cost savings, considering the DDT&E of the SEPS. However, a significant gain in deployment and retrieval capability can be realized for those unique payloads which execeeded the Tug alone capability.

In an effort to improve the overall utilization of resources, space servicing of payloads was analyzed as an operational concept. In-depth analysis of a single program in synchronous equatorial orbit indicated a potential benefit approximating 20 to 45 percent of the program cost, depending upon the servicing policy. However, it was not obvious that these savings could be extrapolated to the full spectrum of payloads in the NASA mission model. There are 13 payload programs in synchronous equatorial orbit (SEO) with one to four satellites in each program. This amounts to a total of 37 satellites at various longitude placements. The baseline MSFC Tug was found to have the performance capability to service up to five satellites distributed over 270 deg of longitude within a seven-day mission period.

The results are based upon a statistical distribution of failures in the candidate satellites which then forces a random loading of space replaceable units (SRUs) on the Tug. The results are preliminary in that only two sample cases could be analyzed, using a manual computation technique. However, several points can be inferred as compared to ground refurbishment of the same payloads.

a. Tug flight operations were reduced by 18 percent.

b. Tug utilization (load factor) averaged 82 percent which is equal to ground refurbishment operations.

c. Total equivalent procurement of payloads was reduced approximately 10 percent. Integrated benefit is 14 percent.

d. Average availability of the satellite systems was 81 percent.

The results point favorably toward space servicing. Also it should be recognized that mission equipment on many of the earth observation satellites typically has a short lifetime of approximately one year. Consequently, equipment changeout or block changes in design can be expected for some time in the future. An operational concept which allows this flexibility without having to replace the entire satellite should be a distinct improvement. In addition, the total satellite weight is not constrained to a retrieval condition of 1, 815 kg (4, 000 lb), allowing some relaxation of the design effort. Once the payload is deployed, the concern focuses on the individual module weights.

The same servicing results may not be possible with low altitude satellites due to orbital regression and reduced traffic to specific orbits. In this case, a multi-mission satellite offers the potential to reduce program costs. A single satellite stationed in a compromise orbit could have the same mission equipment as several satellites in different orbits. In this way, the multi-mission satellite could be serviced by a single Tug or Shuttle operation, replacing failed components and changing out mission equipment. It is recommended that this concept be pursued in future studies as a means of reducing overall system costs.

In summary, this study effort has assessed several operational approaches which could reduce future resource expenditures. Several options appear promising and deserve further investigation. Improved utilization of the Tug, especially for Western Test Range operations, must be pursued to assure a viable alternative to the current launch vehicles. The analysis of space servicing must be continued along with standardization of design approaches. Standardization can be developed without compromising the mission objectives and should provide substantial cost benefits.